Cover Materials Excluding Near Infrared Radiation: Effect on Greenhouse Climate and Plant Processes

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Abstract

Only about half of the energy that enters a greenhouse as sun radiation is in the wavelength range that is useful for photosynthesis (PAR, Photosynthetically Active Radiation). Nearly all the remaining energy fraction is in the Near InfraRed range (NIR) and warms the greenhouse and crop and does contribute to transpiration, none of which is necessarily always desirable. Materials or additives for greenhouse covers that reflect or absorb a part of the NIR radiation have recently become commercially available. Besides lowering greenhouse temperature (which is the primary aim), a NIR-excluding cover has quite a few side-effects, that may become relevant in the passive or semi-passive greenhouses typical of high-energy climates. For instance, the ratio of assimilation to transpiration (the water use efficiency) should increase. By lowering the ventilation requirement, such a cover may hinder in-flow of carbon dioxide, thereby limiting the photosynthesis rate. A previous desk study has shown that in cooler climates such as The Netherlands, a permanent NIR filter may increase year-round energy requirement up to 10%. In this work we present the first results of a rose crop glasshouse experiment with an internal movable, NIR-reflecting screen. We analyse the effect on greenhouse temperature, carbon dioxide management and humidity and on crop transpiration. We then discuss the most appropriate application of a NIR-selective filter, in view of the prevailing climate and the available ambient management option.

INTRODUCTION

Global radiation that enters the greenhouse can be divided into ultraviolet radiation (UV, 300–400 nm), photosynthetically active radiation (PAR, 400–700 nm) and near infrared radiation (NIR, up to 2500 nm). PAR is almost completely (95%) absorbed by the crop and is the source for photosynthesis and thereby crop growth. NIR is partly (50%) reflected by the crop but it is absorbed by installations and construction elements of the greenhouse and increases air (and crop) temperature, as well as does the energy in the PAR range not used for photosynthesis (more then 80% of PAR energy). The heating effect caused by global radiation in greenhouses is desirable during cold periods, but in warm periods the temperature in the greenhouse can increase to undesirable levels so that crop growth and production will be affected or even become impossible. By developing solid materials with NIR-filtering, like plastic films or glass for greenhouses (Verlodt and Verschaeren, 1997; Abdel-Ghany et al., 2001) or sheets to be used as moveable screens (Runkle et al., 2002; Tanaka, 1997) the heat load of the greenhouse can be reduced (Hemming et al., 2005). Also NIR-filtering “whitewash” has been developed (von Elsner and Xie, 2003).

A desk study of Hemming (Hemming et al., 2007) found that permanent NIR filtering in the cover would increase energy consumption in the Dutch climate by 10%, and concluded that movable screens would be more suitable in such conditions. In the experiment whose preliminary results we present here, we compare the effect on the greenhouse climate and crop water use of a NIR reflecting material and a standard material with similar PAR transmission, both installed as movable screens.

MATERIALS AND METHODS

The experiment is being carried out in 4 compartments (144 m^2) of a Venlo-type glasshouse, located in Bleiswijk (52° N, 4.5° E), western part of Holland. The greenhouse is E–W oriented. Each compartment is composed of 2 spans each with north-south width of 4.8 m and east-west length of 15 m. The height of the gutter is 5.5 m and the roof angle is 22°. The soil surface of each compartment is covered with anti-weed sheet, with the exception of a 1.2 m wide, concrete path situated along the entrance of the compartment. Each span is equipped with continuous roof vents, over the whole length and 1.3 m wide, fitted with insect nets, located on both sides of each ridge. Internal movable screens have been installed in the four compartments, two compartments fitted with near infrared (NIR) reflective material (3M, USA) and two with an energy screen (ILS ultra, Ludvig Svensson) of comparable PAR transmittance, for reference. The transmittance of the NIR-reflecting material for diffuse and perpendicular light was measured through an Ulbricht integrating sphere in the range 400 to 1000 nm. Above that range up to 2500 nm we could only measure perpendicular transmittance with a spectrophotometer (Perkin & Elmer). The reference screen selected was the one with the most similar properties in the PAR range, among what is commercially available (Fig. 1). As the ILS ultra is woven, there is a relatively large error in the measurement of perpendicular properties.

In order to reduce maximally the heat load, yet make ventilation possible, 8 rolls of the material were installed internal to each compartment, parallel to the roof, four along the non-opening North (N) and South (S) slopes, and four along the vents. Operation of the screen is controlled as 3 segments: A. in front of the N vent; B. in front of the S vent and C. the rolls facing the fixed part of the roof. All screens are open during night and at daytime whenever greenhouse air temperature is more than 0.3°C below the ventilation set point. When that value is reached, all screens are closed at once to reduce the heat load. When greenhouse air temperature increases above the ventilation set point, the A screens and the N vents are gradually open (P-control). The B screens and the S vents are similarly operated whenever the maximum opening of the N vents is reached and the temperature still exceeds the set point. When ventilation may be reduced, the S vents and screens B are closed first. When greenhouse air temperature decreases to 0.3°C below the ventilation set point all screens are open. The purpose is to maximize effectiveness by keeping the S facing screens closed as long as possible, so as to exclude most (direct) light and energy.

The overall transmittance at crop level for both PAR and global radiation was determined as the average of several spatial samples (taken under diffuse light conditions), with all screens closed, A and B open, and full open. The NIR radiation flux was determined as the difference between global and PAR of each sample, and the transmittance determined accordingly. We measured similarly the reflectance of the full grown crop in both wavelength ranges.

Rooted cutting of cut roses (Rosa hybrida cultivar 'Passion') were planted on March 11th 2008 in rockwool slabs (Grodan) placed on E–W oriented gutters, with a plant density of 5.77 plants/m^2. The plants were grown following the 'bending' technique, which consists in bending over the primary stem and all stems that are not considered useful to flower production. The plants were irrigated by means of a drip system, which was automatically controlled by a fertigation computer, water supply scheduling being based on outside solar radiation and crop age. The nutrient solution pH was adjusted to 5.2 and the EC value was maintained around 1.4–1.6 dS/m. Inside air relative humidity was controlled by a fogging system, the set point decreasing from 85% right after transplanting, to 75%. In the period we discuss here the system was switched off. Inside CO_2 concentration was controlled to 800 ppm (1000 ppm after April 24th) by CO_2 injection during daytime. Artificial lights (100 µmol/m^2/s) were used when there was not enough natural light, and a photoperiod of 17 hours maintained. In order to ensure initially similar crop development, the screening treatments were not applied until the end April. Throughout the growth period, the following climatic data were recorded each minute by the greenhouse control computer system:

(1) The inside air temperature, relative humidity, water vapour deficit and CO_2 concentration were recorded by means of a measuring box, located 1.3 m above ground.
(2) The inside PAR light was measured with a PAR sensor (Quantum sensor) located above

the canopy.
(3) The outside air temperature, RH, solar radiation, wind speed and wind direction were recorded automatically by means of a weather station.
(4) The canopy temperature was measured with an IR thermometer above the canopy.
(5) Position of the screens and ventilators, the valves of the humidification and CO_2 supply, status of the artificial lighting and pipe temperatures were recorded.

Six load cells (model STC-250 kg, Celtron, USA) were installed in each compartment, supporting two coupled gutters, each a half-row long, for a total of 60 plants. The trend of weight decrease allowed determining crop transpiration. As an additional check, the drain from the weighed gutters was recorded through a tipping spoon counter. The cells were logged each minute by a dedicated system.

Besides overall harvest weighing and grading per compartment, of 10 pre-selected plants per compartment we monitored the number of days for each shoot from bud break to harvest, and the number, length and width of harvested shoots. In addition, 3 plants per compartment (except roots) were destructively sampled at 4-week intervals, and leaf area and fresh and dry weight of leaves and shoots were determined. Since the experiment is in progress, we discuss here only the climate and water use data.

RESULTS AND DISCUSSION

As shown in Figure 1, the transmission of the 3M material has a sharp cut-off in the wavelength between 840 and 1120 nm for perpendicular light. Transmission for diffuse light starts decreasing after 650 nm. The diffuse transmission measured in the compartment at flower level for 3 screen positions (open, closed and screens C closed) are shown in table 1. The direct PAR transmission is 87 and 84%, respectively, for the 3M and ILS screen. From these data we have calculated that the NIR screen reduces the NIR energy load by 40% for diffuse and 30% for direct light.

Figure 2 shows relevant climate variables and actuators for two consecutive days (July 3rd, cloudy and July 4th, sunny). The observed differences in climate between the two treatments are small. The main reason for this is that the climate controller, by managing the ventilators, heating and CO_2 supply, is bound to correct any difference that may appear. This means that the actions of the actuators are a better indicator of the effect of the treatment than the climate itself. The opening of the N vent during daytime is proportionally controlled in the range between the set point ventilation 21°C (start opening) and 28°C (100% open). As figure 2 shows, there is hardly any difference in the greenhouse air temperature (Tair) during the 2 days. The mean difference in daytime air temperature between the two treatments is less then 0.2°C and in plant temperature (Tplant) less then 0.1°C. This was the result of an increase of the ventilation by controlling the North vent (shown as Window North). Both days, during daytime, the N vents of the reference compartment were 5 to 10% more open than in the NIR compartment. The transpiration data (see below) have been used to calculate the ventilation flow rate from the vapour balance. The results indicate that the mean ventilation flow is about 4% higher in the reference compartments, against a difference of energy load of up to 20%.

During the first day the CO_2 concentration (CO_2) (Fig. 2) could be controlled around the set point of 1000 ppm. The CO_2 capacity of the supply system was too small to enrich the greenhouse air with CO_2 up to the set point, in view of the increased ventilation of the second day. In both cases the set point was not achieved, though the average daytime CO_2 level is around 50 ppm lower in the reference compartment. As shown in figure 2, there is a slightly (but constantly) higher vapour deficit (VD) in the NIR compartments, which must follow from the lower transpiration rate.

Indeed, the crop transpiration in all 4 compartments, calculated from the load cells data for the same two days, is shown in Figure 3 (left), please refer to global radiation in Figure 2. Night-time transpiration in all compartments was the same, around 25 g/m^2/h. However, in daytime there were obvious differences, getting larger as the radiation increases. As the same amount of irrigation was given, and drain fraction was in all instances above 30%, the differences in transpiration cannot be caused by water stress, and must be related to the lower amount of energy available in the NIR compartments. This is shown by Figure 3 (right), where half-hourly averages of transpiration v sun radiation (as measured by the weather station) are shown for the period of July 1st–13th. The difference in slope among the linear best fits is highly significant. In this stage there were no significant differences in Leaf Area Index (LAI) between the treatments. One may wonder why no differences were detected in plant temperature, following such a difference in transpiration. It seems that the lower amount of energy available has been converted fully into less release of latent heat, so that plant temperature (and sensible heat exchange) has been largely the same under the two screens. Additional plant measurements will tell more about possible morphological adaptations.

With respect to yield it is too early to say anything, since the crop is very young and flowering is still in waves. The present results refer to the end of the 2nd and start of the 3rd harvest, and there has been hardly any yield in this period. Although harvest in the reference compartments started a few days in advance of the NIR compartments, till now no significant differences have been detected in harvest data or in fresh weight of shoot, stem diameter, stem length and percentage neither of blind shoots nor in any of the destructive measurements.

CONCLUSION

It is too early to draw conclusions about the effect of filtering out NIR radiation on yield and quality of yield and crop. The quality of the climate control − and some thermal feedback at plant level − have ensured that there were no relevant differences in the measured climate, and indeed some difference in the ventilation rate has been observed. An accurate energy balance of the compartments would have to be based on information about the ventilation rate, which is not measured. The tendency to lower plant transpiration under the NIR screen seems significant and, if the present absence of effect on yield is confirmed, may result in a significant increase in water use efficiency. This would make such a screen most suitable for arid regions.

The lower humidity caused by reduced crop transpiration does create a potential application for decreasing the costs of energy caused by humidity management in temperate regions, such as the Netherlands.

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Tables

Table 1. Average transmission properties and crop reflection [%] for diffuse light, of the materials themselves, and overall properties of the installations. Properties in the PAR and global range were measured, the NIR flux density was calculated as the difference of the two, and the properties in the NIR range were estimated accordingly (* estimated).

		Material	Open	Closed	All closed	Crop reflection
NIR	PAR	81	43	43	39	5
	NIR	71*	44	42	30	45
	Global	71*	44	43	35	24
	PAR/global		51	53	59	
ILS	PAR	73	45	40	37*	5
	NIR	72*	47	43	40*	45
	Global	72*	46	41	38*	24
	PAR/global		52	51	51*	

Figures

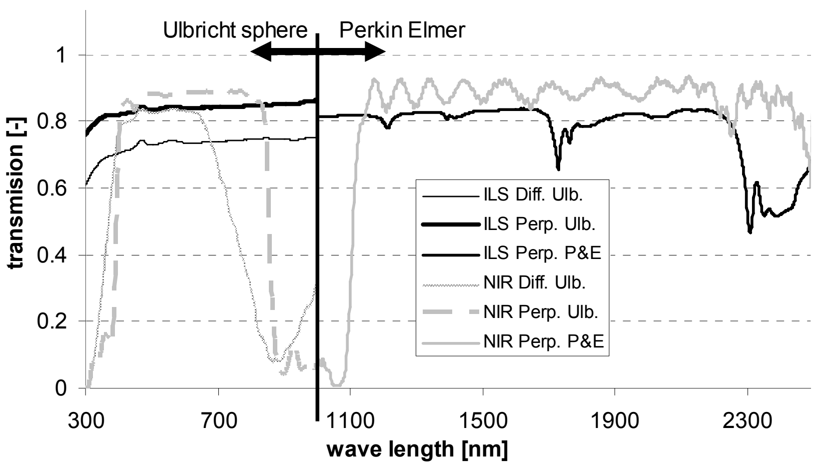

Fig. 1. Diffuse (Diff.) and perpendicular (Perp.) transmission of the ILS ultra (ILS) and 3M NIR (NIR) screen measured in the range of 300–1000 nm with an Ulbricht integrating sphere (Ulb.) and above 1000 nm with a Perkin and Elmer (P&E).

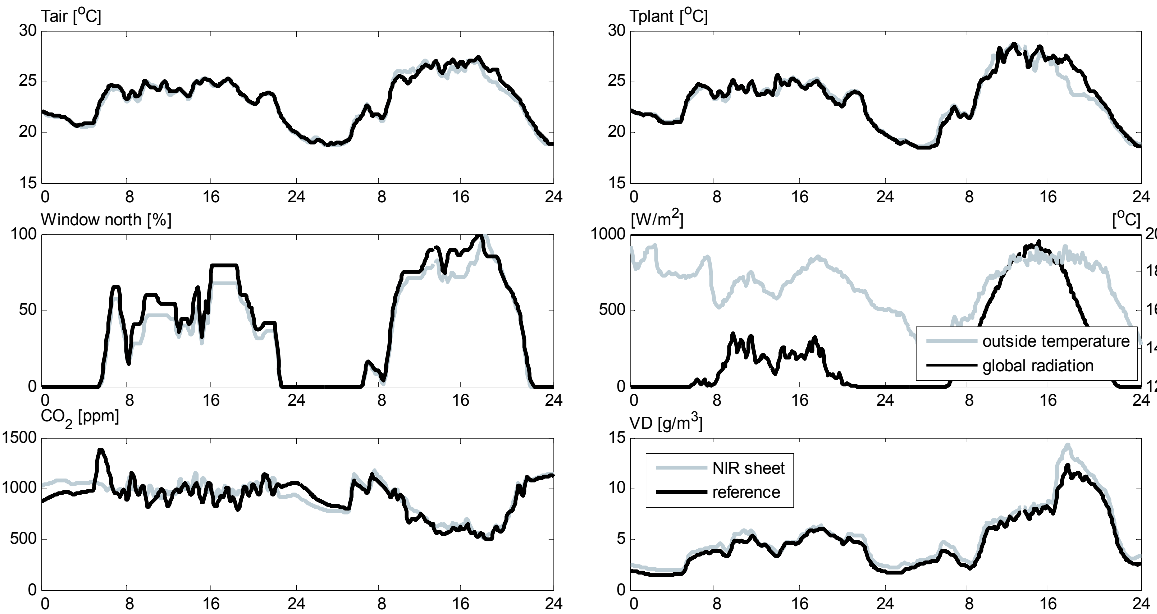

Fig. 2. The air and plant temperature, opening of the North ventilator, global radiation and outside temperature, the CO_2 concentration in the greenhouses and the vapour deficit for July 3rd (cloudy) and 4th (sunny) 2008.

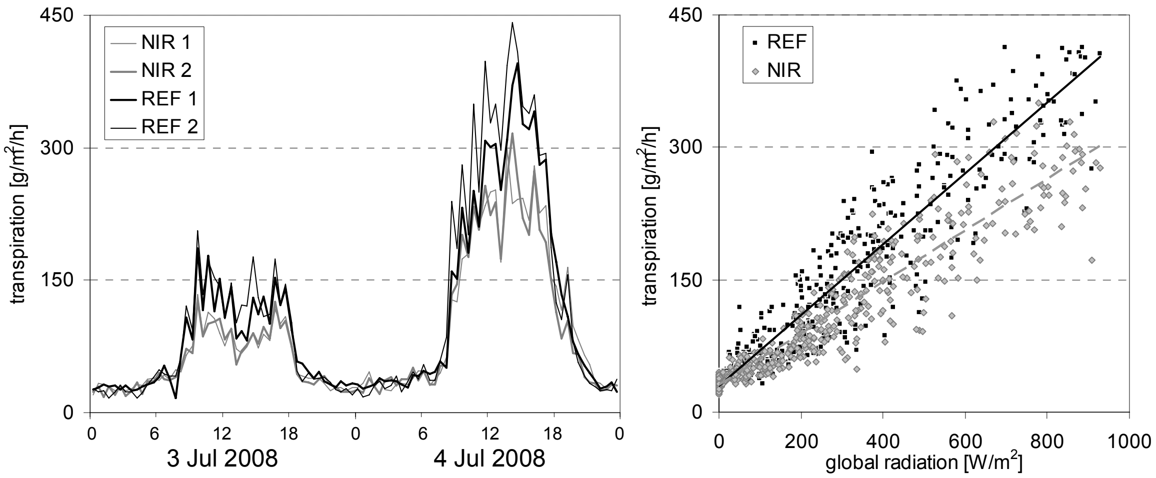

Fig. 3. Left: Transpiration for July 3rd and 4th day for all 4 compartments and Right: half-hourly transpiration versus mean half-hourly global radiation outside, period July 1st–13th.